Australian Government
Department of Defence
Defence Science and
Technology Organisation

Calibration of the Total and Static Pressure Transducers in the DSTO Transonic Wind Tunnel

Stephen S. Lam

Air Vehicles Division
Defence Science and Technology Organisation

DSTO-TN-0960

ABSTRACT

The total and static pressure of the DSTO Transonic Wind Tunnel (TWT) are each measured by a Paroscientific Digiquartz® pressure transducer. As part of the on-going quality management system these transducers have been recalibrated by the National Measurement Institute according to the National Association of Testing Authorities (NATA) standards. From the results of the calibration, zero and span adjustment parameters are determined. These parameters are then applied to the calibration equations supplied by the original equipment manufacturer to correct for the pressure reading. As a result, the standard errors of the total and static pressure are reduced to 0.0027% and 0.0026% of the full-scale reading respectively.

RELEASE LIMITATION

Published by

Air Vehicles Division
DSTO Defence Science and Technology Organisation
506 Lorimer St
Fishermans Bend, Victoria 3207 Australia

Telephone: (03) 9626 7000
Fax: (03) 9626 7999

August 2010

AR-014-821

APPROVED FOR PUBLIC RELEASE

Calibration of the Total and Static Pressure Transducers in the DSTO Transonic Wind Tunnel

Executive Summary

As part of the on-going quality management system of the DSTO Transonic Wind Tunnel (TWT), the transducers used for measuring the total and static pressure in the tunnel test section have been recalibrated to determine their accuracies and reliability. The transducers were independently tested at the National Measurement Institute (NMI), a certified agency of the National Association of Testing Authorities (NATA), and able to carry out high precision calibration of pressure transducers.

Due to the long-term stability shown by this type of transducer, it is not necessary to re-establish all the calibration coefficients. Instead the pressure output, at room temperature, of each of the transducers is compared with the NMI laboratory reference standard over the working range of the TWT. Two adjustment parameters (for span and zero corrections) are estimated using a least squares regression algorithm, and then used to minimise the discrepancies between the output pressure and the "true" pressure indicated by the NMI laboratory reference standard.

The calibration results indicated that the long-term drift of both pressure transducers was less than 1 Pa per year, and was consistent with the test results reported by the manufacturer. The results also showed that before the recalibration, the standard error of the total pressure was approximately 10.0 Pa and that of the static pressure 8.9 Pa. These translate to a maximum uncertainty of approximately 0.0007 in Mach number measurement, and are well within the experimental uncertainties of the wind tunnel.

The adjustment parameters estimated from the calibration are uploaded to the electronic memory of the pressure transducers, and the output pressure then corrected automatically. As a result of the correction, the standard error of the total pressure is reduced to 5.6 Pa (or 0.0027% full scale), and the static pressure to 5.5 Pa (or 0.0026% full scale).

On the basis of these results, the total and static pressure transducers are shown to be reliable and accurate for all the expected test conditions in the DSTO TWT. The performance of these transducers will be monitored and their calibrations reviewed in 12 months as part of the DSTO quality management process.

Author

Stephen S. Lam
Air Vehicles Division

Dr Stephen Lam graduated from University of Melbourne with a Bachelor Degree in Engineering (Mechanical) in 1979, and obtained a Master of Engineering Science Degree in 1982 from the same University after completing a research investigation on the dynamic response of an ocean wave energy absorption device. He later undertook a research study on natural convection in trapezoidal cavities at Monash University, and was awarded the degree of Doctor of Philosophy in 1990 for his findings. Dr Lam joined DSTO in 1988 and has since been working in a variety of wind tunnel research projects. He was appointed as a Senior Research Scientist in 1999, and is currently overseeing all test programs being conducted in the wind tunnel facilities at DSTO Melbourne.

Contents

Notation

DSTO	Defence Science and Technology Organisation
EEPROM	Electrically Erasable Programmable Read-Only Memory
EPROM	Erasable Programmable Read-Only Memory
H	Total pressure (kPa)
M	Mach number
NATA	National Association of Testing Authorities
NMI	National Measurement Institute
P	Applied pressure, Static Pressure (kPa)
PA	Pressure adder adjustment parameter
PM	Pressure multiplier adjustment parameter
RS-232	Recommended Standard 232 of Electronic Industries Association for Telecommunications
S/N	Serial number
TWT	Transonic Wind Tunnel
ΔP	Pressure correction (kPa)

1. Introduction

Total and static pressure are measured in the DSTO Transonic Wind Tunnel (TWT) by two Paroscientific Digiquartz® model 1030A-10 precision absolute pressure transducers, designated as Pt–001 with serial number (S/N) 64672 and Ps–002 with S/N 64675 respectively. As part of the formal quality management in the TWT, the accuracies of these transducers were determined and documented, following the testing by the National Measurement Institute (NMI), a certified agency by the National Association of Testing Authorities (NATA).

The original equipment manufacturer's calibration of the Digiquartz pressure sensor involves mounting the transducer in a temperature-controlled chamber and applying known pressures from primary standards to the transducer over its entire operation temperature range (–40 to +50 deg C). A total of 14 calibration coefficients are then determined to form the equations that characterise the pressure reading from the transducer's signals. The calibration equations used to calculate the pressure from the measured signals are given in [1] and are also shown in Appendix A. A full calibration involves repeating this process and re-establishing the values of all 14 calibration coefficients. This process is both costly and time consuming.

Due to diverse application and user requirements Paroscientific does not specify a typical interval between calibrations of their Digiquartz transducers. However, long-term stability testing of three of their barometric range of pressure transducers at their laboratories showed a median drift rate of only –0.6 Pa per year [2]. Furthermore, their experiences with more than 100,000 high pressure depth sensors over 30 years in oceanographic deployments showed that the calibration characteristics of the sensor did not change significantly with time [3]. The only recommended corrections are minor adjustments to the parameters, PA (Pressure Adder) and, PM (Pressure Multiplier). Sea-Bird Electronics, Inc. demonstrated that using these adjustment parameters the corrected data error is approximately 0.0002% when compared with a transducer that has undergone a full recalibration by Paroscientific [4]. These tests also showed that the 'slope' (PM) and 'offset' (PA) corrections derived at 20 deg C can account for long-term drift to less than 0.01% of the sensor's full-scale range.

On the basis of these experiences, the methodology used to recalibrate the DSTO TWT pressure transducers is to determine the PA and PM adjustment parameters, rather than re-establishing all the calibration coefficients. This can be achieved by direct comparisons of the pressure outputs from the transducers with a NATA certified pressure reference. The NMI is one such laboratory, and was able to provide a high precision reference pressure for such purposes. The pressure range covered in the calibration is from 40 to 200 kPa absolute.

2. Transducer Interface Requirements

The Paroscientific Digiquartz model 1030A-10 pressure transducer is equipped with an intelligent transmitter which consists of a digital interface board with a microprocessor-controlled counter and RS-232 port. The microprocessor operating program is stored in the permanent memory (EPROM) while user controllable parameters such as calibration coefficients and correction factors are stored in writable memory (EEPROM). The user communicates with the microprocessor operating program via the two-way RS-232 interface which differs from the normal RS-232 port in the following aspects:

1. The power (between +6 to +25 VDC) to the transducer is supplied via pins 9 and 5, as shown in Figure 1.

TRANSDUCER CONNECTOR	
PIN NO.	DESCRIPTION
2	DATA TO COMPUTER, RX
3	DATA FROM COMPUTER, TX
5	GROUND, GND
9	POWER, +6 TO 18 VDC

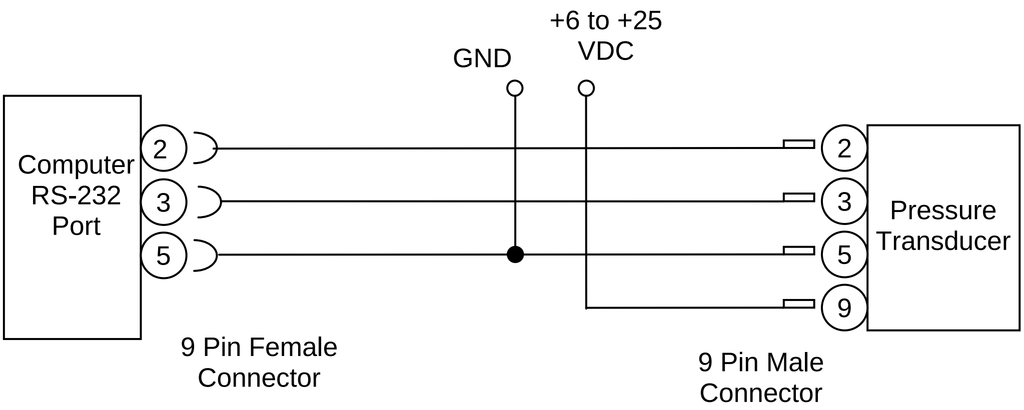

Figure 1 Pin-outs assignment for connecting a computer's RS-232 port to a single Digiquartz pressure transducer

2. Multiple Digiquartz transducers may be connected to a single RS-232 port on the user's computer using special adaptors, as detailed in [1]. Alternatively custom-made cable can be manufactured, following the wiring schematic provided in [1], to achieve the same purpose. One such cable, shown in Figure 2, was made to connect two Digiquartz pressure transducers simultaneously to a computer. The wiring schematic of this custom-made cable is shown in Figure 3.

Figure 2 A custom-made cable for connecting 2 Digiquartz pressure transducers to the RS-232 port of a computer. The red and black bare wires are to be connected to the positive and ground terminals of a +6 to +25 VDC power suppler.

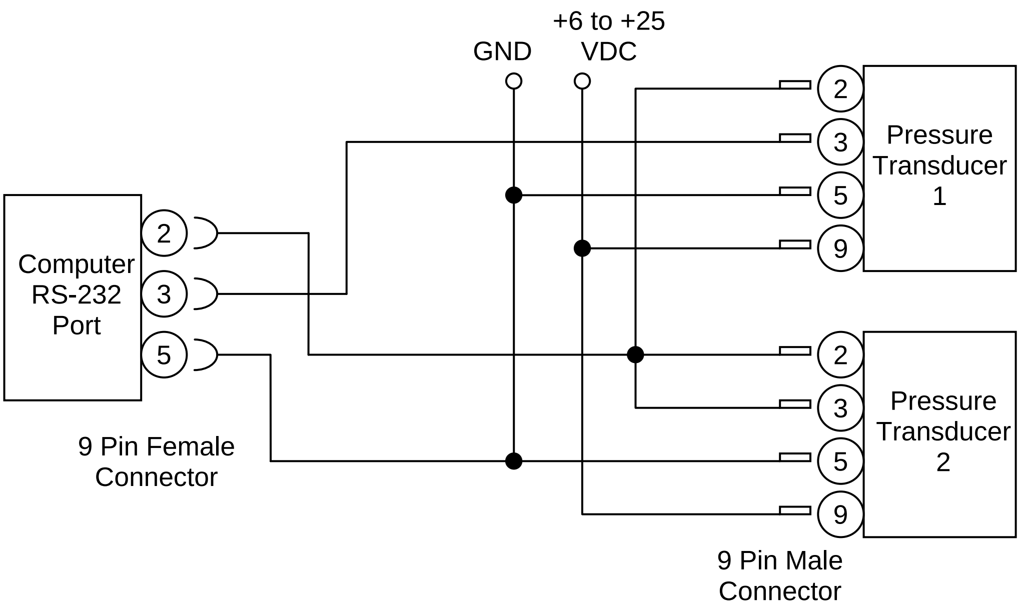

Figure 3 Schematics of wiring of the custom-made cable for connecting two Digiquartz pressure transducers to the RS-232 port of a computer

3. Digiquartz Pressure Monitoring Software

Paroscientific provides free *Digiquartz Interactive 2.0* software to communicate with the Digiquartz pressure transducer, but the software does not allow simultaneous sampling and recording of readings for more than one transducer. The author has written a Microsoft Excel Visual Basic Application macro, `digiMon.XLS`, to facilitate the monitoring and sampling of pressure readings for up to four transducers.

The serial communication in `digiMon.XLS` is handled by the ActiveX control `MSCOMM32.OCX` which is not part of the Microsoft Windows operating system. It is, however, included as part of the installation of Microsoft's Visual Studio or Visual Basic software. If a system does not have the file `MSCOMM32.OCX` installed, it can be copied to the folder:

`C:\Windows\System32`,

and then be registered in the system with the command:

```
regsvr32 mscomm32.ocx
```

In mid-2009, Microsoft implemented new measures to register ActiveX controls in its Windows suite of operating systems, which has made the above file obsolete and it could no longer be used if the Windows operating system were updated. If this is the case, then the new version of ActiveX control files can be installed using the following procedure:

1. Install Microsoft Visual Basic version 6.0 on a Windows XP system.
2. Apply the cumulative update rollup for the Visual Basic 6.0 Service Pack 6. The file required is `VB60SP6-KB957924-v2-x86-ENU.msi` which can be downloaded from the Microsoft website.
3. After the update, three new files related to the `MSCOMM32` ActiveX control will be installed in the `C:\Windows\System32` folder. The files are:

   ```
   MSComm32.ocx
   MSCOmm32.dep
   MSComm.srg
   ```

4. These files can be copied to another PC on which `digiMon.XLS` is to be used, and placed in the `C:\Windows\System32` folder.
5. Finally, register the control in the system with the command:

   ```
   regsvr32 mscomm32.ocx
   ```

The `digiMon.XLS` macro samples and captures both the period and the pressure readings of the Digiquartz pressure transducers in an Excel workbook for post-processing.

4. Calibration Procedures

The DSTO TWT pressure transducers were calibrated by direct comparison with the NMI laboratory reference standards, in accordance with the test method published by the Metrology Society of Australia [5].

The set up included a manual pressure controller supplying calibration pressures to the reference dead weight tester. The controller was then isolated to allow stable pressures to be supplied from the dead weight tester at each test point. Both transducers were connected simultaneously via a short tube to the dead weight tester. Absolute pressures were applied up to 100 kPa using the dead weight tester as the absolute standard. From 100 kPa to 200 kPa the dead weight tester was used as a gauge standard in conjunction with a precision barometer. The data includes the 100 kPa (nominal) overlap points to confirm repeatability. The uncertainty of the applied pressures was 3.3 Pa.

The calibration process consisted of applying pressures starting at nominally 0 kPa then increasing to a maximum of 200 kPa. From 40 kPa to 200 kPa, and at 15 kPa intervals, an average of 10 readings was recorded from each of the 2 Digiquartz pressure transducers together with the NMI laboratory pressure standard. The applied pressure was then decreased progressively in the second pass, from 200 kPa down to 0 kPa. The sampling of the pressure readings was again taken at 15 kPa intervals between 200 kPa and 40 kPa. The above process was repeated giving a total of 4 calibration passes to provide repeatability and hysteresis information.

5. Calibration Results

As a result of the calibration, the reports comparing the measured value with the reference applied pressures, and the "averaged correction" required at each calibration point for each transducer was produced by NMI [6, 7]. These reports are attached in Appendices C and D. In addition, the average values of the sampled calibration data were also supplied by NMI in Microsoft Excel files. These data were used to produce the adjustment parameters (as described in section 5.2) required to minimise the discrepancies between the measured and the reference pressures.

5.1 Tables of Calibration Data

The readings (in the units Pa) of both DSTO transducers compared with the reference pressure standard at each calibration pass are given in Tables 1 to 4.

Table 1 Comparisons of pressure readings with the Reference Standard. Calibration Pass 1 – Pressure was increased progressively from 0 kPa to 200 kPa

Pass 1	Pt–001 (S/N 64675)		Ps–002 (S/N 64672)	
Reference Pressure P (Pa)	Measured Pressure (X) Pa	Correction ΔP (Pa)	Measured Pressure (X) Pa	Correction ΔP (Pa)
39927.4	39935.7	-8.3	39939.9	-12.5
55109.7	55117.5	-7.8	55121.9	-12.2
70000.2	70007.0	-6.8	70012.3	-12.1
84890.3	84892.1	-1.8	84900.3	-10.0
100073.4	100071.6	1.8	100079.5	-6.1
100785.0	100777.0	8.0	100806.1	-21.1
115794.8	115801.4	-6.6	115818.1	-23.3
130691.1	130688.7	2.4	130709.1	-18.0
145578.7	145571.8	6.9	145601.8	-23.1
160768.0	160756.7	11.3	160795.7	-27.7
175672.2	175656.4	15.8	175706.3	-34.1
190596.7	190585.6	11.1	190641.7	-45.0
200830.9	200810.6	20.3	200871.1	-40.2

Table 2 Comparisons of pressure readings with the Reference Standard. Calibration Pass 2 – Pressure was decreased progressively from 200 kPa to 0 kPa

Pass 2	Pt–001 (S/N 64675)		Ps–002 (S/N 64672)	
Reference Pressure P (Pa)	Measured Pressure (X) Pa	Correction ΔP (Pa)	Measured Pressure (X) Pa	Correction ΔP (Pa)
39926.6	39925.3	1.3	39945.9	-19.3
55108.5	55105.4	3.1	55126.9	-18.4
69999.6	69997.3	2.3	70016.8	-17.2
84889.4	84884.9	4.5	84904.9	-15.5
100071.2	100069.5	1.7	100085.6	-14.4
100775.0	100766.5	8.5	100796.1	-21.1
115878.9	115865.7	13.2	115896.2	-17.3
130773.1	130754.1	19.0	130789.3	-16.2
145657.8	145636.6	21.2	145679.6	-21.8
160835.1	160813.6	21.5	160862.9	-27.8
175724.3	175701.9	22.4	175756.9	-32.6
190602.8	190583.4	19.4	190641.1	-38.3

Table 3 Comparisons of pressure readings with the Reference Standard. Calibration Pass 3 – Pressure was increased progressively from 0 kPa to 200 kPa

Pass 3	Pt–001 (S/N 64675)		Ps–002 (S/N 64672)	
Reference Pressure P (Pa)	Measured Pressure (X) Pa	Correction ΔP (Pa)	Measured Pressure (X) Pa	Correction ΔP (Pa)
39925.0	39936.2	-11.2	39939.5	-14.5
55107.0	55119.0	-12.0	55123.2	-16.2
69998.8	70008.9	-10.1	70015.8	-17.0
84888.3	84894.7	-6.4	84906.8	-18.5
100071.2	100074.1	-2.9	100088.8	-17.6
100764.0	100757.1	6.9	100784.9	-20.9
115860.9	115854.0	6.9	115880.7	-19.8
130743.2	130737.1	6.1	130762.4	-19.2
145633.8	145626.2	7.6	145657.6	-23.8
160811.1	160800.8	10.3	160840.5	-29.4
175705.3	175690.7	14.6	175738.9	-33.6
190593.9	190577.1	16.8	190632.5	-38.6
200815.1	200797.5	17.6	200858.1	-43.0

Table 4 Comparisons of pressure readings with the Reference Standard. Calibration Pass 4 – Pressure was decreased progressively from 200 kPa to 0 kPa

Pass 4	Pt–001 (S/N 64675)		Ps–002 (S/N 64672)	
Reference Pressure P (Pa)	Measured Pressure (X) Pa	Correction ΔP (Pa)	Measured Pressure (X) Pa	Correction ΔP (Pa)
39926.5	39926.6	-0.1	39952.8	-26.2
55108.7	55106.1	2.6	55133.5	-24.8
69998.4	69998.1	0.3	70022.0	-23.6
84889.1	84890.2	-1.1	84912.0	-22.9
100071.7	100075.5	-3.8	100092.7	-21.0
100782.0	100775.8	6.2	100806.0	-24.0
115885.9	115876.8	9.1	115908.1	-22.2
130764.2	130748.9	15.3	130783.9	-19.7
145646.8	145627.1	19.7	145670.8	-24.0
160828.2	160807.0	21.2	160857.3	-29.1
175708.4	175688.0	20.4	175741.7	-33.3
190594.9	190577.1	17.8	190635.4	-40.5

Plots of the correction value, ΔP, as applied to the transducers at each calibration pressure, P, are shown in Figures 4 and 5 respectively for Pt–001 and Ps–002.

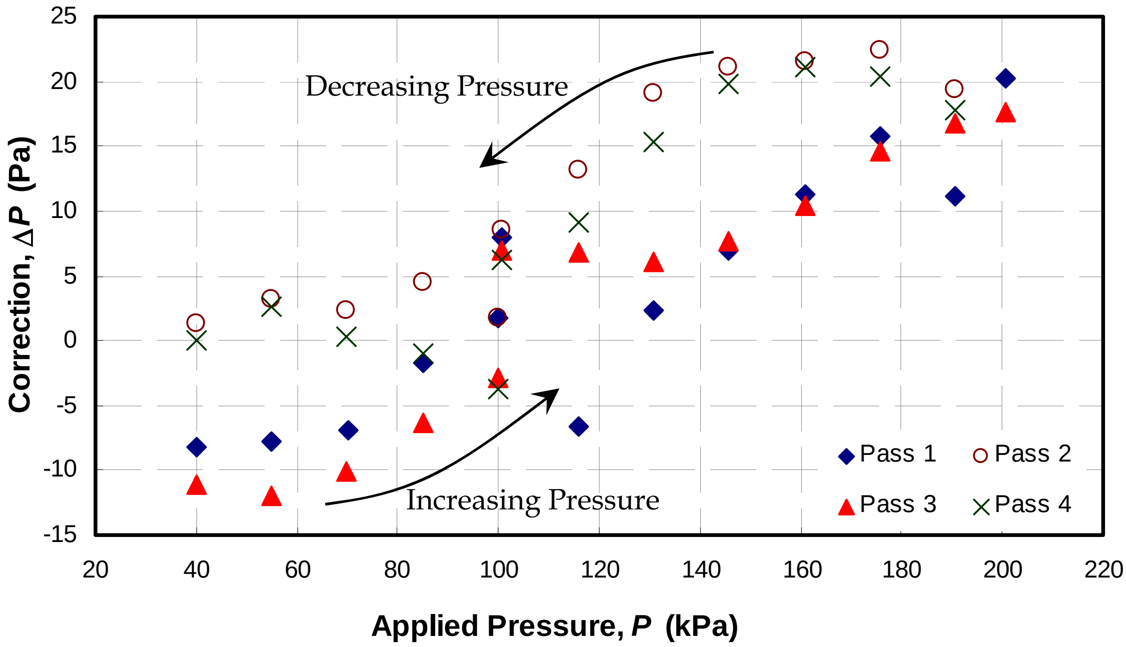

Figure 4 The variation of pressure correction, ΔP, with applied pressure, P, for the Pt–001 total pressure transducer (S/N 64675)

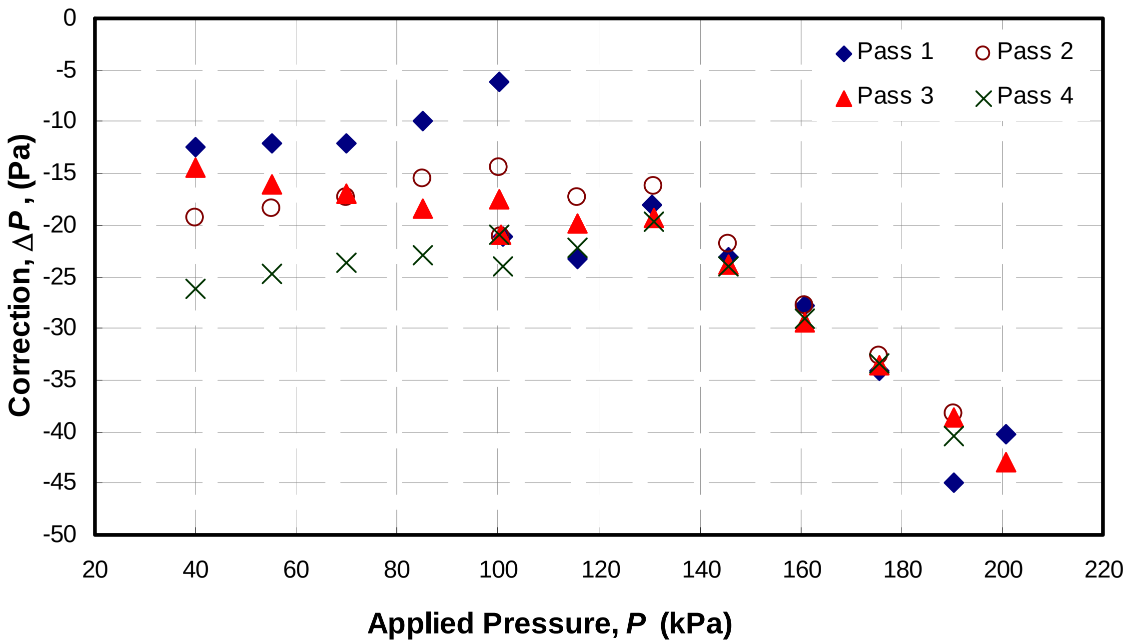

Figure 5 The variation of pressure correction, ΔP, with applied pressure, P, for the Ps–002 static pressure transducer (S/N 64672)

Figures 4 and 5 show that the two transducers exhibit very different characteristics in terms of pressure correction, Δ*P*, over the range of calibration pressure, *P*.

The Pt–001 transducer showed substantial hysteresis in the readings between increasing and decreasing applied pressure (Figure 4). The difference in Δ*P* for a given *P* can be as high as 20 Pa. However, generally speaking, there was a linear correlation between ΔP and P, in which ΔP increases as P increases.

Conversely, transducer Ps–002, exhibits less hysteresis over the range 135 kPa $\leq P \leq$ 200 kPa. However, there is a change in gradient between sub-atmospheric and super-atmospheric pressures. At P > 120 kPa, ΔP decreases linearly with increasing P.

The standard errors of Pt–001 and Ps–002 from the calibration results were 10.0 and 8.9 Pa respectively. While their calibrations have been checked in 2005 [8], these transducers had not been recalibrated since their purchase in the 1990s. Therefore the drift rates are less than 1 Pa per year (assuming that the standard errors are both zero at the time of purchase), and are comparable to those reported by Paroscientific [2].

5.2 Effects of Pressure Variations on Mach Number

The measurement of total and static pressure in the DSTO TWT are used in the determination of Mach number. The effects of errors in these pressures can be shown by the following analysis.

The Mach number, M, in wind tunnel is calculated according to the equation

$$M^2 = 5\left\{\left(\frac{P}{H}\right)^{-\frac{2}{7}} - 1\right\} \tag{1}$$

where P is the static pressure (measured by Ps–002) and H the total pressure (measured by Pt–001).

Differentiating this equation partially yields

$$\Delta M = \frac{5}{2M}\left\{-\frac{2}{7}P^{-\frac{9}{7}}H^{\frac{2}{7}}\Delta P + \frac{2}{7}P^{-\frac{2}{7}}H^{-\frac{5}{7}}\Delta H\right\} \tag{2}$$

where ΔM is the error in Mach number, ΔH is the error in total pressure, and ΔP is the error in static pressure. The error in Mach number, ΔM, for a given test condition is then evaluated according to this equation using the average of the correction values listed in Tables 1 to 4. The results for some typical test conditions are tabulated in Table 5.

Table 5 Error in Mach number due to variations in total and static pressures under typical operation conditions in the DSTO TWT

M = 0.40				
***H* (kPa)**	***P* (kPa)**	***ΔH* (kPa)**	***ΔP* (kPa)**	***ΔM***
40	35.82	0.010	0.023	-0.00072
55	49.26	0.010	0.022	-0.00049
70	62.69	0.008	0.022	-0.00044
85	76.13	0.004	0.020	-0.00040
100	89.56	0.001	0.020	-0.00039
115	103.00	0.011	0.018	-0.00015
130	116.43	0.017	0.020	-0.00008
145	129.86	0.021	0.018	0.00001
160	143.30	0.021	0.023	-0.00005
175	156.73	0.021	0.029	-0.00012
190	170.17	0.019	0.034	-0.00018
200	179.12	0.019	0.042	-0.00026

M = 0.60				
***H* (kPa)**	***P* (kPa)**	***ΔH* (kPa)**	***ΔP* (kPa)**	***ΔM***
40	31.36	0.010	0.023	-0.00062
55	43.12	0.010	0.022	-0.00042
70	54.88	0.008	0.022	-0.00037
85	66.64	0.004	0.020	-0.00032
100	78.40	0.001	0.020	-0.00031
115	90.16	0.011	0.018	-0.00013
130	101.92	0.017	0.020	-0.00008
145	113.68	0.021	0.018	-0.00002
160	125.44	0.021	0.023	-0.00007
175	137.20	0.021	0.029	-0.00012
190	148.96	0.019	0.034	-0.00016
200	156.80	0.019	0.042	-0.00022

M = 0.80				
***H* (kPa)**	***P* (kPa)**	***ΔH* (kPa)**	***ΔP* (kPa)**	***ΔM***
40	26.24	0.010	0.023	-0.00063
55	36.08	0.010	0.022	-0.00043
70	45.92	0.008	0.022	-0.00037
85	55.76	0.004	0.020	-0.00031
100	65.60	0.001	0.020	-0.00030
115	75.44	0.011	0.018	-0.00014
130	85.28	0.017	0.020	-0.00010
145	95.12	0.021	0.018	-0.00004
160	104.96	0.021	0.023	-0.00009
175	114.80	0.021	0.029	-0.00013
190	124.64	0.019	0.034	-0.00017
200	131.20	0.019	0.042	-0.00023

M = 1.00				
***H* (kPa)**	***P* (kPa)**	***ΔH* (kPa)**	***ΔP* (kPa)**	***ΔM***
40	21.13	0.010	0.023	-0.00072
55	29.06	0.010	0.022	-0.00049
70	36.98	0.008	0.022	-0.00041
85	44.90	0.004	0.020	-0.00034
100	52.83	0.001	0.020	-0.00032
115	60.75	0.011	0.018	-0.00017
130	68.68	0.017	0.020	-0.00014
145	76.60	0.021	0.018	-0.00008
160	84.53	0.021	0.023	-0.00012
175	92.45	0.021	0.029	-0.00017
190	100.37	0.019	0.034	-0.00020
200	105.66	0.019	0.042	-0.00026

M = 1.20				
***H* (kPa)**	***P* (kPa)**	***ΔH* (kPa)**	***ΔP* (kPa)**	***ΔM***
40	16.50	0.010	0.023	-0.00088
55	22.68	0.010	0.022	-0.00060
70	28.87	0.008	0.022	-0.00050
85	35.05	0.004	0.020	-0.00040
100	41.24	0.001	0.020	-0.00036
115	47.42	0.011	0.018	-0.00022
130	53.61	0.017	0.020	-0.00019
145	59.79	0.021	0.018	-0.00012
160	65.98	0.021	0.023	-0.00017
175	72.17	0.021	0.029	-0.00022
190	78.35	0.019	0.034	-0.00026
200	82.48	0.019	0.042	-0.00032

These errors in Mach number can be graphically represented, as shown in Figure 6.

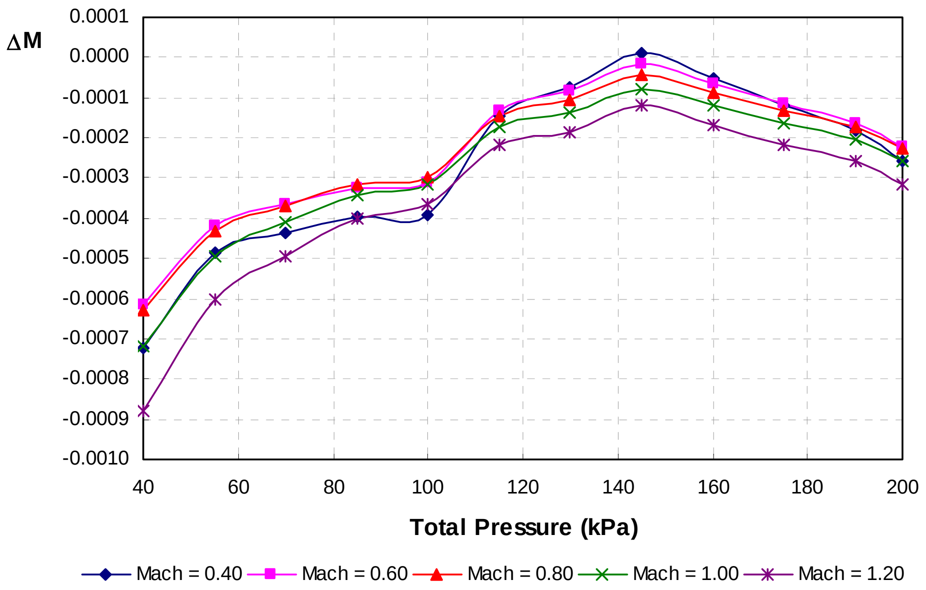

Figure 6 Error in Mach number caused by variations in total and static pressure readings

Figure 6 shows that the maximum error in Mach number occurs at sub-atmospheric conditions. From past experience, the lowest total pressure the wind tunnel is likely to operate is 50 kPa. Hence, at these conditions, the magnitude of the maximum likely error in Mach number would be below 0.0007. Since the tolerance of the Mach number set-point is typically 0.002, the maximum error in Mach number is well within the experimental uncertainty.

5.3 Adjustment Parameters

The correction factors are expressed in terms of a Pressure Adder (PA) and a Pressure Multiplier (PM), and are applied to the measured value according to the following equation:

$$P_{\text{adjusted}} = \text{PM} \times (P_{\text{measured}} + \text{PA}) \tag{3}$$

The adjustment parameters PA and PM were estimated from the calibration data using a least squares regression algorithm, described below.

In equation (4), let Y_i be the sequence of true pressures applied to the transducer, and X_i be the corresponding pressure values measured by the transducer, where $i = 1, \ldots, n$, and n is the number of calibration points. Applying these parameters to the measured pressures according to equation (3) theoretically adjusts the values to be equal to the true pressures:

$$Y_i = \text{PM} \times (X_i + \text{PA}) \qquad i = 1, \ldots, n \tag{4}$$

Applying the least squares linear regression to the set of Y_i and X_i values, the PM and PA values are given by:

$$\mathrm{PM} = \frac{\sum Y_i X_i - \dfrac{\left(\sum Y_i\right)\left(\sum X_i\right)}{n}}{\sum X_i^2 - \dfrac{\left(\sum X_i\right)^2}{n}} \tag{5}$$

$$\mathrm{PA} = \frac{\dfrac{\sum Y_i}{n} - \mathrm{PM}\dfrac{\sum X_i}{n}}{\mathrm{PM}} \tag{6}$$

It should be noted that the pressure unit defined in both pressure transducers is expressed in pounds per square inch (psi). Hence before applying the regression equations (5) and (6), the data in Table 1 must be converted to psi units by dividing the pressure readings by the conversion factor 6894.757 (1 psi ≡ 6894.757 Pa).

The least squares regression algorithm is then applied to the data for all four calibration passes simultaneously. The PM and PA values for both transducers are obtained as in Table 6.

Table 6 Calibration adjustment parameters PA and PM for the pressure transducers.

	Pt–001 (S/N 64675)	Ps–002 (S/N 64672)
PM =	1.00070	0.9998551
PA =	–0.0019326	–0.0009185

When the PA and PM parameters are applied, the standard error of Pt–001 is reduced to 5.6 Pa, and Ps–002 to 5.5 Pa. In terms of percentage of full-scale reading (206843 Pa), the standard errors are 0.0027% for Pt–001 and 0.0026% for Ps–002.

5.4 Applying the Correction Parameters

For the adjustment parameters PA and PM to take effect, their values must be uploaded to the Electrically Erasable Programmable Read-Only Memory (EEPROM) for each transducer as "User Calibration Coefficients". Instructions for modifying the PA and PM parameters are described in the programming and operation manual of the Digiquartz transducer [1]. Paroscientific also provides the *Digiquartz Interactive 2.0* software, available from their website, which can be used to change the values of the parameters. In brief the procedure is:

1. Select the "Configuration and Monitoring" option on the *Digiquartz Interactive 2.0* start up window (Figure 7), and click the "Next >>" button.

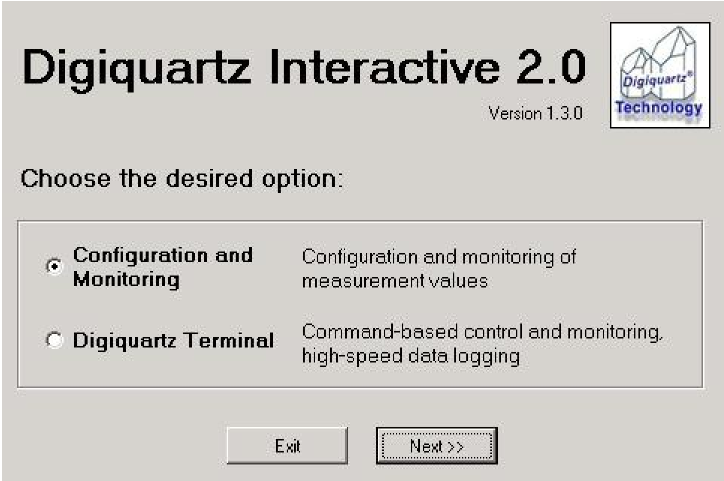

Figure 7 The Digiquartz Interactive 2.0 start up window

2. Select the "Begin Search" button to establish communication with the Digiquartz transducers connected to the computer (Figure 8).

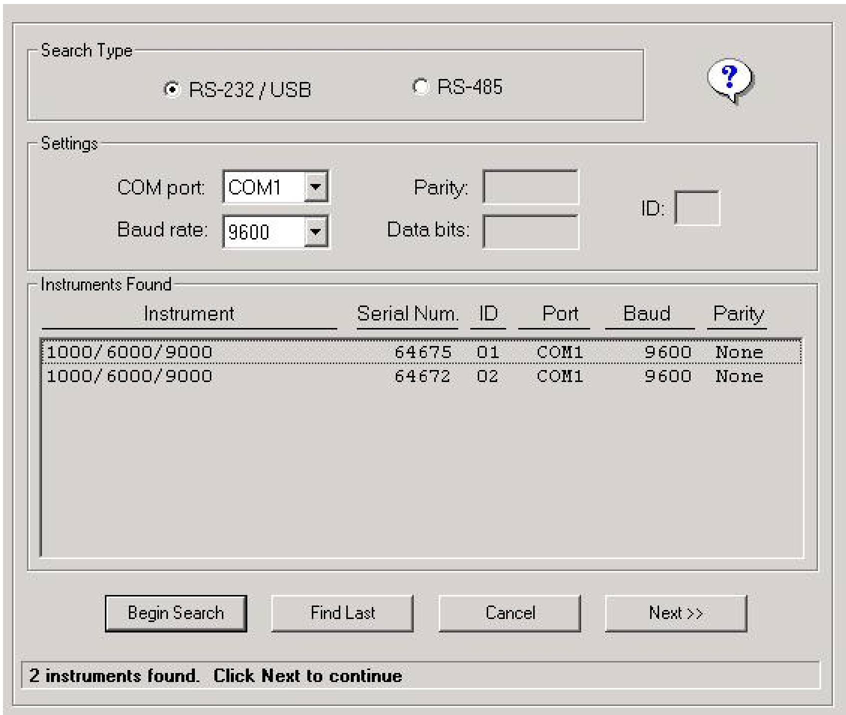

Figure 8 Establishing communication with Pressure Transducers using the Digiquartz Interactive 2.0 software

The default communication settings are:

- RS-232/USB
- COM port: COM1
- Baud rate: 9600

When communication is established, the serial number of the transducers should appear on the "Instruments Found" panel. Click the "Next >>" button to proceed to the next step.

3. From the "Configuration" tab of the windows shown in Figure 9, select the transducer with the matching serial number (SN) to which the correction parameters apply. On the left hand panel click the + symbol next to "Calibration" to expand the selection. Choose "User Coefficients" by clicking on the item. Two text input boxes will appear on the right hand panel.

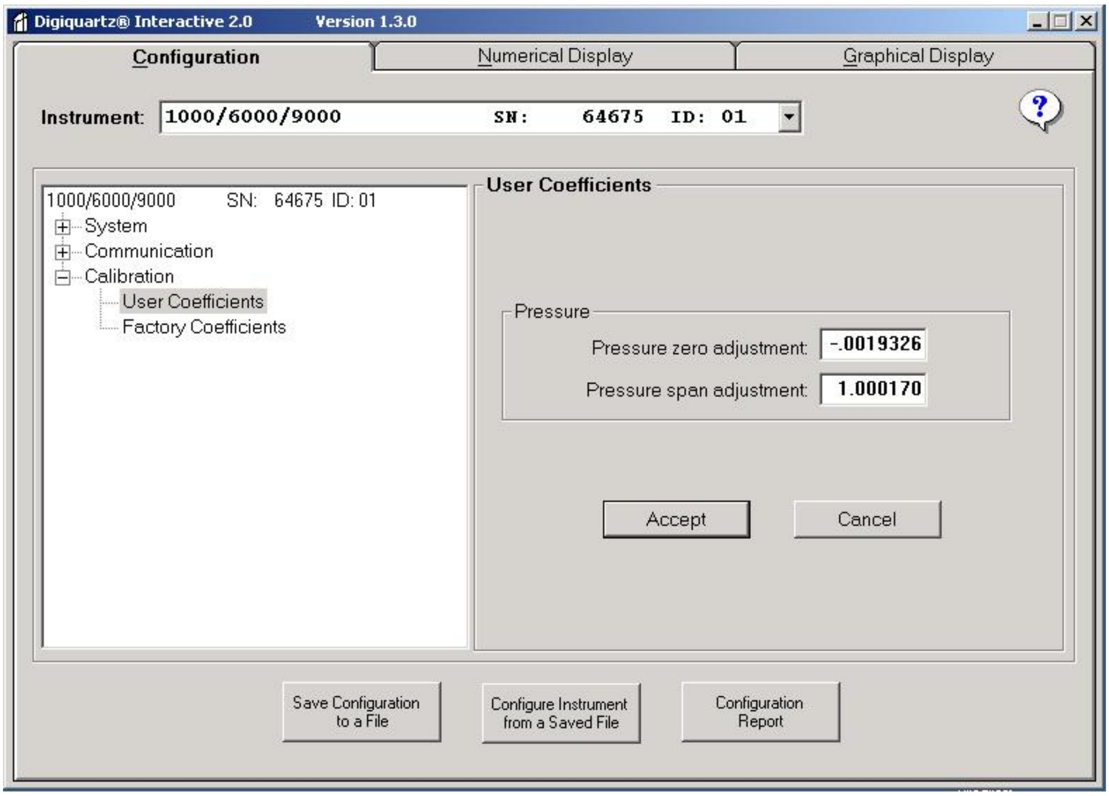

Figure 9 Uploading the values of PA and PM as "User Coefficients". PA is labelled as "Pressure zero adjustment" and PM is the "Pressure span adjustment".

4. Enter the PA value to the box labelled "Pressure zero adjustment", and the PM value to the box labelled "Pressure span adjustment". Note that the maximum number of digits allowed for each entry, not including the sign and the decimal point, is seven.

5. Click the "Accept" button to effect the change, and click "OK" to confirm the change when prompted.

Once these new parameters are uploaded they will be stored in the EEPROM of the transducer and the pressure reading output from the transducer will be adjusted accordingly.

6. Conclusions

The transducers used to measure the total and static pressures in the DSTO TWT have been calibrated in the laboratory of the NMI. The calibration data showed that the standard error of the total pressure measured in the tunnel was 10.0 Pa, and that of the static pressure 8.9 Pa. These represent a drift of less than 1 Pa per year for both transducers, comparable to that reported by Paroscientific. Prior to the calibration the errors in the total and static pressure measurements were translated to a maximum uncertainty in Mach number of approximately 0.0007, well within the experimental uncertainties of the wind tunnel.

From the calibration data, the zero and span adjustment parameters (PA and PM) for each of the pressure transducers were then evaluated using the least squares regression algorithm. These parameters have been uploaded to the EEPROM of the corresponding transducers. As a result, the estimated standard error of the total pressure is reduced to 5.6 Pa (0.0027% full scale), and that of the static pressure to 5.5 Pa (0.0026% full scale).

7. Acknowledgements

The author would like to acknowledge the assistance of Mr Owen Holland, Mr Christopher Rider and Mr Howard Quick in the calibration process. The professional service and advice provided by Mr Neville Owen and his team at the laboratory of National Measurement Institute is also greatly appreciated.

8. References

[1] "*Digiquartz Precision Pressure Instruments – Programming and Operation Manual*". Paroscientific, Inc. Document No. 8107-001, Revision G, Dec 1992.

[2] Schuchman, W. "*Nineteen-Year Test of Barometer Long-Term Stability*", Paroscientific, Inc. http://www.paroscientific.com/pdf/G8806-001_WEB.pdf. Feb 2008.

[3] "*Calibration of Digiquartz® Instruments*". Paroscientific, Inc. http://www.paroscientific.com/pdf/calibration.pdf.

[4] "*Re-Calibration of Paroscientific Digiquartz Pressure Sensor*". Sea-Bird Electronics Inc. Application Note No. 20. June 1980.

[5] "*Calibration of Pressure Calibrators, Indicators and Transducers*". Metrology Society of Australia MSA Test Method 1 – 2008, Revision No. 5, June 2008.

[6] Owen, N. "*Measurement Report on A Digital Pressure Transducer Serial Number 64675*". National Measurement Institute Measurement Report Number RN091029. 22 Oct 2009.

[7] Owen, N. "*Measurement Report on A Digital Pressure Transducer Serial Number 64672*". National Measurement Institute Measurement Report Number RN091030. 22 Oct 2009.

[8] Lam, S., Clayton, J., and Holland, O. "*Calibration of the Digiquartz Pressure Transducer in the Transonic Wind Tunnel*". DSTO Wind Tunnel Internal Working Document, October 2005.

Appendix A Calibration Equations of the Digiquartz Pressure Transducer

The Digiquartz Pressure Transducer model 1030A-10 incorporates an intelligent transmitter that calculates pressure and temperature from the period of two frequency signals. A force-sensitive quartz crystal inside the transducer responds to the applied pressure by changing its period of oscillation and output a pressure frequency signal. A second frequency (period) output signal comes from a quartz crystal temperature sensor, and is used for thermal compensation. The pressure and temperature are related to these signals by the following equations [1]:

$$\text{Pressure (psi)} = C\left(1-\frac{T_0^2}{\tau^2}\right)\left[1-D\left(1-\frac{T_0^2}{\tau^2}\right)\right] \tag{A1}$$

$$\text{Temperature (deg C)} = Y_1 U + Y_2 U^2 + Y_3 U^3 \tag{A2}$$

where τ = pressure period in microseconds

U = (temperature period) – U_0 microseconds

$$C = C_1 + C_2 U + C_3 U^2$$

$$D = D_1 + D_2 U$$

$$T_0 = T_1 + T_2 U + T_3 U^2 + T_4 U^3 + T_5 U^4$$

The calibration coefficients for the transducer are:

Pressure coefficients:	C_1, C_2, C_3, D_1, D_2, T_1, T_2, T_3, T_4, and T_5
Temperature coefficients:	U_0, Y_1, Y_2, and Y_3

These coefficients are stored in the Electrically Erasable Programmable Read-Only Memory (EEPROM) of the transducer. The final output pressure is computed from the above formulas using the following equation:

$$P_{output} = \text{PM}\left[(\text{units multiplier}) \times \text{Pressure} + \text{PA}\right] \tag{A3}$$

where "Pressure" is calculated according to equation (A1), PA is a pressure zero adjustment parameter, and PM a pressure span adjustment parameter. These parameters are also stored in the EEPROM and can be changed via the appropriate interactive software. The "units multiplier" depends on the unit of pressure selected by the user for output. The DSTO TWT data acquisition and control system (ASE2000) is set up to accept the pressure in psi units from these transducers; hence the units multiplier has a value of 1.

The values of the calibration coefficients and other configuration information for each of these pressure transducers are listed in Appendices E and F.

Appendix B   RS-232 Pin Assignments

Most computer RS-232 ports have either male or female 25-pin or 9-pin connectors. The most common computer pin connections are tabulated below.

Table B1   RS-232 pin assignments for a 9-pin and a 25-pin connector

IBM PC 9-pin		STANDARD RS-232 25-pin	
3	Data from computer	2	Data from computer
2	Data to computer	3	Data to computer
5	Signal ground	7	Signal ground
4	Data Terminal Ready	20	Data Terminal Ready
8	Clear To Send	5	Clear To Send
6	Data Set Ready	6	Data Set Ready
1	Data Carrier Detect	8	Data Carrier Detect
		1	Frame ground

These connections are all that required to provide proper interface between a Digiquartz pressure transmitter and a computer.

Appendix C NMI Measurement Report RN091029

Australian Government

National Measurement Institute

MEASUREMENT REPORT ON

A Digital Pressure Transducer

Serial Number 64675

This document is issued in accordance with NATA's accreditation requirements.
Accredited for compliance with ISO/IEC 17025.
Accreditation Number 1.

The National Measurement Institute is responsible for Australia's units and standards of measurement. The measurement results presented in this report are traceable to Australia's primary standards.

1/153 Bertie Street
Port Melbourne VIC 3207
Australia

Telephone: +61 3 9644 4888
Facsimile: +61 3 9644 4900

For further information contact: **Mr Neville Owen**

Telephone: +613 9644 4907
Email: neville.owen@measurement.gov.au

Ref.: **RN091029** *File:* **CB/09/2043** *Checked:* *Date:* **22 October 2009**

For:	Defence Science & Technology Organisation 506 Lorimer Street Fishermens Bend VIC 3207
Reference:	Quote number Q091029 dated 7 September 2009
Description:	Digital pressure transducer with computer interface
Identification:	Serial Number: 64675
Manufacturer:	Parascientific
Operating range:	0 to 30 psi absolute
Pressure fluid:	Nitrogen
Previous examination:	N/A
Date of test:	14 October 2009 to 16 October 2009

Test Details

The pressure transducer was calibrated at the National Measurement Institute, Melbourne by direct comparison against laboratory reference standards, in accordance with test method HAFAM-25 *Calibration of Pressure Measuring Devices* version 4. During testing the environment temperature was: (20 ± 0.3)°C.

The pressure transducer was connected to a computer and data was logged using the software digiMon v1.0.xls provided by the client. At each test point a sample of 10 readings was collected and averaged to provide the transducer reading.

Results

The pressure transducer reading at the tested pressure was found to require the corrections given in Table 1.

Table 1

Nominal Applied Pressure	**Average Reading**		**Average Correction**	
	Increasing	Decreasing	Increasing	Decreasing
kPaA	kPaA	kPaA	kPaA	kPaA
39.926	39.936	39.925	- 0.010	+ 0.001
55.108	55.118	55.105	- 0.010	+ 0.003
69.999	70.007	69.998	- 0.008	+ 0.001
84.889	84.893	84.887	- 0.004	+ 0.002
100.072	100.073	100.073	- 0.001	- 0.001
115.855	115.855	115.844	0.000	+ 0.011
130.743	130.739	130.726	+ 0.004	+ 0.017
145.629	145.622	145.608	+ 0.007	+ 0.021
160.811	160.800	160.790	+ 0.011	+ 0.021
175.703	175.688	175.682	+ 0.015	+ 0.021
190.597	190.583	190.578	+ 0.014	+ 0.019
200.823	200.804		+ 0.019	

Notes

1. When the sign of the correction is positive (+) the correction should be added to the barometer reading and when negative (-) subtracted, to give the correct pressure.

2. The corrections in Table 1 have been determined as the average of corrections from increasing and decreasing readings.

Uncertainty

The values in Table 1 have been reported with an uncertainty of:

$\pm$ 0.046 kPa with a coverage factor k = 2.1

The uncertainties stated in this report have been calculated in accordance with principles in the ISO Guide to the Expression of Uncertainty in Measurement, and give intervals estimated to have a level of confidence of 95%.

The uncertainty applies at the time of measurement only and takes no account of any drift or other effects that may apply afterwards. When estimating the uncertainty at any later time, other relevant information should also be considered, including, where possible, the history of the performance of the instrument and the manufacturer's specifications.

Neville Owen

Mr Neville Owen
for Dr L M Besley
Chief Metrologist

Neville Owen

Mr Neville Owen
NATA Approved Signatory

Appendix D NMI Measurement Report RN091030

Australian Government

National Measurement Institute

MEASUREMENT REPORT ON

A Digital Pressure Transducer

Serial Number 64672

NATA
WORLD RECOGNISED ACCREDITATION

This document is issued in accordance with NATA's accreditation requirements.

Accredited for compliance with ISO/IEC 17025.

Accreditation Number 1.

The National Measurement Institute is responsible for Australia's units and standards of measurement.
The measurement results presented in this report are traceable to Australia's primary standards.

1/153 Bertie Street
Port Melbourne VIC 3207
Australia

Telephone: +61 3 9644 4888
Facsimile: +61 3 9644 4900

For further information contact: **Mr Neville Owen**

Telephone: +613 9644 4907
Email: neville.owen@measurement.gov.au

Ref.: **RN091030** *File:* **CB/09/2044** *Checked:* *Date:* **22 October 2009**

For:	Defence Science & Technology Organisation 506 Lorimer Street Fishermans Bend VIC 3207
Reference:	Quote number Q091030 dated 10 September 2009
Description:	Digital pressure transducer with computer interface
Identification:	Serial Number: 64672
Manufacturer:	Parascientific
Operating range:	0 to 30 psi absolute
Pressure fluid:	Nitrogen
Previous examination:	none
Date of test:	14 October 2009 to 16 October 2009

Test Details

The pressure transducer was calibrated at the National Measurement Institute, Melbourne by direct comparison against laboratory reference standards, in accordance with test method HAFAM-25 *Calibration of Pressure Measuring Devices* version 4. During testing the environment temperature was: (20 ± 0.3)°C.

The pressure transducer was connected to a computer and data was logged using the software digiMon v1.0.xls provided by the client. At each test point a sample of 10 readings was collected and averaged to provide the transducer reading.

Results

The pressure transducer reading at the tested pressure was found to require the corrections given in Table 1.

Table 1

Nominal Applied Pressure	**Average Reading** Increasing	Decreasing	**Average Correction** Increasing	Decreasing
kPaA	kPaA	kPaA	kPaA	kPaA
39.926	39.940	39.949	- 0.014	- 0.023
55.108	55.122	55.130	- 0.014	- 0.022
69.999	70.014	70.019	- 0.015	- 0.020
84.889	84.903	84.908	- 0.014	- 0.019
100.072	100.084	100.090	- 0.012	- 0.018
115.855	115.877	115.875	- 0.022	- 0.020
130.743	130.762	130.761	- 0.019	- 0.018
145.629	145.652	145.652	- 0.023	- 0.023
160.811	160.840	160.840	- 0.029	- 0.029
175.703	175.737	175.736	- 0.034	- 0.033
190.597	190.639	190.636	- 0.042	- 0.039
200.823	200.865		- 0.042	

Notes

1. When the sign of the correction is positive (+) the correction should be added to the barometer reading and when negative (-) subtracted, to give the correct pressure.

2. The corrections in Table 1 have been determined as the average of corrections from increasing and decreasing readings.

Ref.: RN091030 *File:* CB/09/2044 *Checked:* [signature] *Date:* 22 October 2009

Uncertainty

The values in Table 1 have been reported with an uncertainty of:

$\pm$ 0.048 kPa with a coverage factor k = 2.1

The uncertainties stated in this report have been calculated in accordance with principles in the ISO Guide to the Expression of Uncertainty in Measurement, and give intervals estimated to have a level of confidence of 95%.

The uncertainty applies at the time of measurement only and takes no account of any drift or other effects that may apply afterwards. When estimating the uncertainty at any later time, other relevant information should also be considered, including, where possible, the history of the performance of the instrument and the manufacturer's specifications.

Mr Neville Owen
for Dr L M Besley
Chief Metrologist

Mr Neville Owen
NATA Approved Signatory

Appendix E Configuration Data of Pt–001

PAROSCIENTIFIC CONFIGURATION REPORT

Model: 1000/6000/9000
Serial Number: 64675
Device ID: 01
Baud Rate: 9600

Date: 18/11/2009
Time: 2:55:38 PM

CALIBRATION COEFFICIENTS

Coef	Value	Description
C1	167.6382	C1 coefficient
C2	9.204993	C2 coefficient
C3	-324.0730	C3 coefficient
D1	.0414423	D1 coefficient
D2	.0000000	D2 coefficient
T1	27.62899	T1 coefficient
T2	.6789815	T2 coefficient
T3	14.86394	T3 coefficient
T4	-159.5455	T4 coefficient
T5	253.2211	T5 coefficient
U0	5.859992	U0 coefficient
Y1	-3959.871	Y1 coefficient
Y2	-13264.83	Y2 coefficient
Y3	-141408.0	Y3 coefficient
PA	.0000000	Pressure adder
PM	1.000000	Pressure multiplier
TC	.6781685	Timebase correction factor

CONFIGURATION PARAMETERS

Parm	Value	Description
DP	6	Number of decimal places in displayed pressure value
MD	0	Serial mode
OP	31.00000	Overpressure alarm setpoint
PR	00019	Pressure resolution
SN	64675	Serial number
TR	00076	Temperature resolution
UF	1.000000	User-defined pressure unit factor
UN	1	Pressure unit
VR	S2.02	Firmware version
ZL	0	Enable/disable tare
ZS	0	Tare switch state
ZV	.0000000	Tare offset value

Appendix F Configuration Data of Ps–002

PAROSCIENTIFIC CONFIGURATION REPORT

Model: 1000/6000/9000
Serial Number: 64672
Device ID: 02
Baud Rate: 9600

Date: 18/11/2009
Time: 2:55:55 PM

CALIBRATION COEFFICIENTS

Coef	Value	Description
C1	158.7935	C1 coefficient
C2	10.86927	C2 coefficient
C3	-201.7834	C3 coefficient
D1	.0376878	D1 coefficient
D2	.0000000	D2 coefficient
T1	27.74521	T1 coefficient
T2	.5994950	T2 coefficient
T3	15.99242	T3 coefficient
T4	-84.52063	T4 coefficient
T5	195.9677	T5 coefficient
U0	5.887649	U0 coefficient
Y1	-3938.363	Y1 coefficient
Y2	-13088.78	Y2 coefficient
Y3	-139067.2	Y3 coefficient
PA	.0000000	Pressure adder
PM	1.000000	Pressure multiplier
TC	.6781637	Timebase correction factor

CONFIGURATION PARAMETERS

Parm	Value	Description
DP	6	Number of decimal places in displayed pressure value
MD	0	Serial mode
OP	31.00000	Overpressure alarm setpoint
PR	00019	Pressure resolution
SN	64672	Serial number
TR	00076	Temperature resolution
UF	1.000000	User-defined pressure unit factor
UN	1	Pressure unit
VR	S2.02	Firmware version
ZL	0	Enable/disable tare
ZS	0	Tare switch state
ZV	.0000000	Tare offset value

DEFENCE SCIENCE AND TECHNOLOGY ORGANISATION
DOCUMENT CONTROL DATA

	1. PRIVACY MARKING/CAVEAT (OF DOCUMENT)
2. TITLE Calibration of the Total and Static Pressure Transducers in the DSTO Transonic Wind Tunnel	3. SECURITY CLASSIFICATION (FOR UNCLASSIFIED REPORTS THAT ARE LIMITED RELEASE USE (L) NEXT TO DOCUMENT CLASSIFICATION) Document (U) Title (U) Abstract (U)
4. AUTHOR(S) Stephen S. Lam	5. CORPORATE AUTHOR DSTO Defence Science and Technology Organisation 506 Lorimer St Fishermans Bend Victoria 3207 Australia

6a. DSTO NUMBER	6b. AR NUMBER	6c. TYPE OF REPORT	7. DOCUMENT DATE
DSTO-TN-0960	AR-014-821	Technical Note	August 2010

8. FILE NUMBER	9. TASK NUMBER	10. TASK SPONSOR	11. NO. OF PAGES	12. NO. OF REFERENCES
2009/1174415/1	AVD.4	CAVD	28	8

13. URL on the World Wide Web	14. RELEASE AUTHORITY
http://www.dsto.defence.gov.au/corporate/reports/DSTO-TN-0960.pdf	Chief, Air Vehicles Division

15. SECONDARY RELEASE STATEMENT OF THIS DOCUMENT

Approved for public release

OVERSEAS ENQUIRIES OUTSIDE STATED LIMITATIONS SHOULD BE REFERRED THROUGH DOCUMENT EXCHANGE, PO BOX 1500, EDINBURGH, SA 5111

16. DELIBERATE ANNOUNCEMENT

No Limitations

17. CITATION IN OTHER DOCUMENTS Yes

18. DSTO RESEARCH LIBRARY THESAURUS http://web-vic.dsto.defence.gov.au/workareas/library/resources/dsto_thesaurus.shtml

Quality Management
Calibration
Transducers
Pressure measurements
Wind tunnels

19. ABSTRACT

The total and static pressure in the DSTO Transonic Wind Tunnel are each measured by a Paroscientific Digiquartz® pressure transducer. As part of the on-going quality management these transducers have been recalibrated by the National Measurement Institutue according to the National Association of Testing Authorities (NATA) standards. From the results of the calibration, zero and span adjustment parameters are determined. These parameters are then applied to the calibration equations supplied by the orignial equipment manufacturer to correct the pressure reading. As a result, the standard errors of the total and static pressure are reduced to 0.0027% and 0.0026% of full scale reading respectively.